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FACTORS AFFECTING THE PERSISTENCE OF INSECTICIDES IN SOIL

by

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In the past two decades large quantities of insecticidal chemicals have been applied to agricultural soils or have reached them indirectly. In a recent survey of 21 potato fields in Britain dieldrin was found in 17, DDT in 14 and aldrin in 9; the largest residues were about 2 lb active ingredient (a.i.) of DDT, 1 lb a.i. of dieldrin and 0.3 lb a.i. of aldrin (Wheatley *et al*, 1962). Strickland *et al* (1962) estimated that 27% of the potato crops grown in 1960 were treated with aldrin, and Gould *et al* (1962) found that 26% of a sample of 216 pea fields investigated had been sprayed with DDT between 1957 and 1959. In orchards, as much as 10 lb a.i. of DDT may be sprayed annually to control caterpillars and a considerable proportion of this falls on the soil below the trees.

Much of the insecticides present in agricultural soils comes from foliage sprays which miss their targets and fall onto the soil, either close to the plants or after drifting, especially as very fine mists from the low-volume sprays now commonly used. It has been estimated that probably as much as 50% of sprayed chemicals ultimately end up in soil either in this way or by being washed off the foliage. Large quantities of insecticides to control soil-inhabiting pests are applied as sprays or dusts to the soil surface, and later cultivated into the soil, or are combined with the fertilizer before it is distributed, or arecoated on seeds before planting.

The insecticide residues most common in soil are chlorinated hydrocarbons; the organophosphorus and other insecticides in current use break down so rapidly that measurable quantities exist in soil for only days, weeks or months after they are applied. Calculations made from published and unpublished results (Edwards, 1963) show that of the chlorinated hydrocarbons, on average, DDT persists longest, about 80% remaining after one year. After the same time 75% of dieldrin, 60% of lindane, 55% of chlordane, 45% of heptachlor and 26% of aldrin originally applied may be still present. After three years these residues have diminished to about 50% for DDT, 40% for dieldrin, 15% for chlordane, 10% for heptachlor and 5% for aldrin. Aldrin and heptachlor may be effective for longer than these figures indicate, however, because their breakdown products—dieldrin and heptachlor epoxide, respectively—not included in the above figures, are also insecticidal. By contrast, lindane may be less effective than the figures show, because it breaks down to non-insecticidal chemicals that still show by the methods of analysis usually used. Soil insecticides, however, have very variable persistence; for instance, although the average proportion of DDT remaining after three years is about 50% this can range from 26 to 78%. It is important to note that chemicals may still be found in soil long after any biological effects are observable.

The mechanisms of disappearance of insecticides from soil are poorly understood; volatilization, microbial activity, leaching, oxidation and uptake by plants probably all contribute. Climatic and soil factors such as soil type, temperature and rainfall, that are considered here, may affect several of these mechanisms, and so although I list them independently, their effects are complex and interlinked. The factors sometimes act all in the same direction, or may oppose one another, so that the same insecticide may persist much longer in some soils or climates. Some of these factors are reasonably well understood; others are considered here almost for the first time.

1. *Soil type and organic-matter content*

Some of the earliest work on the persistence of insecticides in different soil types was by Fleming & Maines (1953, 1954), who concluded that the persistence of DDT and chlordane in soil was inversely related to the amount of organic matter in the soil. They estimated the organic matter in soil from the percentage nitrogen present and most of their determinations of insecticide residues were by bioassay. Edwards *et al* (1957) found that the amount of aldrin and lindane remaining in soil was closely correlated with the percentage of organic matter present, but only slightly correlated with the moisture-holding capacity of the soil. Insecticide was adsorbed least in Springfield sand and then by increasing amounts in silty clay loam, light sandy clay loam, coarse silt, silty clay, sandy loam, loam, clay loam and muck. As much as 30 times the amount of lindane and 15 times the amount of aldrin was necessary to give the same kill of fruit flies exposed to sand containing the insecticide, as to muck soil.

Young & Rawlins (1958) supported this conclusion. They sprayed different soils with heptachlor once a week for six weeks, and found that only 31% of the total amount applied was present one week after the last application in muck soil, 11% in a silty clay loam and 8% in a silt loam. Lichtenstein & Schulz (1959, 1960) treated different soils with insecticides, and 3½ years after treatment they recovered 1.43 times more DDT, 4.25 times more aldrin and 8.45 times more lindane from a muck soil than from a comparably treated Miami silt loam. They concluded that the two major factors affecting the persistence of an insecticide in soils were the amount of organic matter in a particular soil and the climatic conditions of the area. Harris & Lichtenstein (1961) found that insecticides volatilized at different rates from soil of different types; aldrin and lindane volatilized much more rapidly from a quartz sand than from a muck soil. In Great Britain Wheatley *et al* (1960) estimated that dieldrin applied to control carrot fly in a mineral soil at Wellesbourne had what they termed a "half-life" of about 4 years, whereas in fen soil the "half-life" was about 5-7 years.

The soil type not only influences the disappearance of insecticides, but also the rate of conversion into other insecticidally active chemicals; for instance Lichtenstein & Schulz (1960) found that aldrin was readily transformed into dieldrin in a Carrington Loam, but less rapidly in a muck soil, and Harris & Lichtenstein (1961) showed that more dieldrin was formed in a given time in silt loam soils than in sands or sandy loams. They thought this was because the loss of aldrin as vapour from soils decreased as the soils contained more clay and organic matter.

Thus there seems little doubt that the amount of organic matter in soil is a major factor affecting persistence of insecticides and that soils containing much organic matter, although needing more insecticide to kill pests, retain the chemical much longer than soils poorer in organic matter. Clay content also may affect insecticidal persistence, but in a more erratic way that is still poorly understood.

2. *Cultivation*

Insecticides applied to control soil-borne pests are usually cultivated into the soil immediately after they are applied, whereas that falling from foliage sprays may remain undisturbed for weeks or months, hence the persistence of residues from the two different kinds of treatment can differ greatly. Wheatley *et al* (1961) found that 95% of a dosage of 1 lb a.i. per acre of aldrin applied to the surface of sandy loam soil disappeared in six weeks during summer, little being transformed into dieldrin; by contrast when the insecticide was mixed into the soil, 40% remained as aldrin and 10% as dieldrin 20 weeks after treatment. Lichtenstein *et al* (1962) found that residues of aldrin and heptachlor applied to the soil surface ranged from 2.7 to 5.3% of the applied dosages after 4 months, but when the insecticide was roto-tilled into the soil 10 times as much remained. Lichtenstein & Schulz (1961) showed that regular cultivation could decrease amounts of insecticides in soil; they disked a loam soil treated with 4 lb a.i. of DDT or aldrin per acre daily for 3 months and found that the residues of DDT diminished by 25% and those of aldrin by 38%.

The depth to which the insecticide is incorporated into the soil also affects its persistence; Young & Rawlins (1958) raked weekly applications of heptachlor superficially into soil with a hand rake, but found that this had little influence on the length of time the insecticide persisted. They found however that by thoroughly mixing heptachlor with soil in large containers in the laboratory, the amount remaining after 21 months was 53% as compared with 26% which remained in field plots treated at the same time.

It is very difficult to mix insecticides deep into the soil; Edwards (unpublished data) rotovated soil sprayed with insecticide, to a depth of 9 inches, in two directions at right angles to each other, and found that 46.5% was in the top inch of soil, 40.5% in the second, 10.2% in the third, 1.4% in the fourth inch and only 1.4% had penetrated below a depth of four inches. Wheatley & Hardman (1959) also showed that dieldrin was not mixed in to the full depth of cultivation when rotovated in, and found that plowing was more effective than rotovation in getting insecticides deep into soil, but it is doubtful if insecticides are distributed evenly in the vertical plane by plowing.

All the available evidence indicates that the persistence of insecticides in soil depends on how thoroughly and how deeply they are mixed into the soil; even very persistent chemicals disappear during a period of months when left on the soil surface.

3. *Rainfall and soil moisture*

The persistent insecticides are very insoluble in water, but particles may be physically washed down through crevices into deeper soil. Allen *et al* (1954) applied DDT to soil, worked it into the soil to a depth of 6 inches, and four years later took cores of soil which they separated into 2-inch deep layers and analysed them separately for residues. The top 6 inches of soil still contained 87% of the residues, the next 2 inches a further 9.5% and the remaining 3.5% was in the bottom 2 inches. Lichtenstein (1958) treated a Miami silt loam and a muck soil with aldrin, lindane or DDT and rototilled them into a depth of 4-5 inches. After seventeen months, 84-96% of the insecticides were still in the top 3 inches of the loam soil, 4-12% between 3 and 6 inches deep and 0-5% below this, whereas in the muck soil 62-74% was in the top layer, 19-29% between 3 and 6 inches and 7-8% in the 6-9-inch layer. In another experiment (1962) six soils were treated with aldrin or heptachlor at 1, 2 and 3 lb a.i. per acre, rotovated to a depth of 5 inches and

assayed after 12 months. The upper 3 inches of soil contained 90% of the insecticidal residues, and the remainder was in the 3-6-inch layer. After three years, however, 72-82% of the residues recovered were in the upper 3 inches of soil and only very small amounts in the 6-9-inch layer. Young & Rawlins (1958) found that heptachlor applied to the surface was not leached to a depth of more than 3 inches after 9 months.

In laboratory experiments in which water was poured through columns of soil there was some slight leaching of lindane, but the insecticide could not be detected in water collected at the bottom of the column; less insecticide was leached from soils with much organic matter than from mineral soils with less.

Drenches of DDT were applied to steeply sloping plots by Edwards (unpublished data), and samples were analysed for residues after twelve months. There was more insecticide in the lower halves of the plots than in the upper halves, but the differences were not significant although there was insecticide in untreated soil lower down the slope. In a similar experiment Lichtenstein (1958) found 1.3-2.2 times more insecticide in the lower half of sloping plots than in the upper half after three years, with DDT showing smaller differences than lindane or aldrin, and with the greatest differences in the most steeply sloping plots. These differences, however, are most probably caused by surface run-off from one plot to another. It seems that, in general, leaching is responsible for little loss of chlorinated-hydrocarbon insecticides and does not carry much to deeper soil.

Rainfall may affect the persistence of soil insecticides in other ways than by leaching. Harris & Lichtenstein (1961) found that aldrin volatilized faster from wet than from dry soils; it was three times faster from wet than from dry sand. Lindane, and to a lesser extent dieldrin, broke down faster in wet than in dry soils, but the disappearance of DDT from soil was unaffected by the moisture content. The rate at which aldrin volatilized from dry soils was not proportional to the mineral or organic-matter content of the soils; but in moist soils the rate decreased as organic matter increased. Not only did aldrin persist longer in dry soil than in wet soil, but less was converted to dieldrin in the dry than in the moist soil.

4. *Temperature and sunshine*

Insecticides are probably mainly lost from soil by volatilization, chemical degradation, or bacterial decomposition; all these processes are affected by temperature. Edwards kept samples of soil treated with insecticides for two and a half years at –10°C and for shorter times at 0°C with no significant losses. Lichtenstein & Schulz (1959a) found that insecticides were not lost from frozen soils, but at 6°C 16-27% of aldrin or heptachlor was lost in 56 days, at 26°C 51-55% and at 46°C between 86-98%. The same authors (1959b) found aldrin was not transformed to dieldrin at 7°C, but 4-8% was changed to dieldrin at 26°C or 46°C.

Temperatures in unshaded surface soil in summer are often high and insecticides can be expected to break down more slowly in soil shaded from sun by foliage than in exposed soil. Young & Rawlins (1958) found more heptachlor was lost from soil exposed to the sun than from artificially shaded soil; the difference in temperature between shaded and unshaded areas was sometimes as much as 14°C (25°F). Lichtenstein *et al* (1962) found two to three times more aldrin or heptachlor residues in alfalfa-covered than in fallowed plots, three years after soil treatment.

High temperatures alone must be expected to cause insecticides to break down more rapidly in tropical than in temperate soils, especially during the wet season; but when the soil becomes very dry the rate of breakdown could be considerably slowed. Many parts of the United States have hot summers and cold winters and insecticides could persist in soil there for comparable times to more temperate countries such as Great Britain.

5. *Concentration and formulation of insecticide*

The dosages of the different insecticides used in experiments to test their persistence in soil differ widely. Some workers have applied massive doses sometimes exceeding 100 lb a.i. per acre to simulate accumulations, others have used more realistic, intermediate dosages of the order of 10 lb a.i. and some only the sort of dose recommended for a single field application. It has not been at all clear from these scattered observations how the amount of insecticide applied affects its persistence in soil, so I have plotted all the published results together with some unpublished, as graphs of percentage of original dose against time. Regression lines showed that proportionately more disappeared each year from a small than from a large dose. But larger actual quantities of insecticide disappeared from soil treated with a large than a small dose, i.e. the rate of breakdown does not appear to remain constant irrespective of dose, but falls off logarithmically. The rate at which a particular dosage disappears seems to be reasonably constant whether the insecticide is a residue of a much larger dose or a new application, except for the rather rapid losses that seem to occur immediately after insecticide is applied.

There is little information in the literature on how formulation affects the persistence of soil insecticides. Young & Rawlins (1958) found that heptachlor disappeared faster when applied as wettable powder than as an emulsion, but gave no explanation for this. Mulla (1961) obtained better control of eye gnats using sprays of DDT than with granular formulations containing the same amount of insecticide, 3 months after treatment. Probably insecticides applied as sprays disappear sooner than dusts because the initial volatilization is faster, but dusts may be lost as drift.

6. *Microbial populations*

The breakdown of weed killers in soil has been much more extensively studied than of insecticides, and the soil microflora seems mainly responsible for most of the metabolism of these chemicals (Evans, 1963). There have been few corresponding studies on disappearance of insecticides, but Bollen *et al* (1958) thought that microorganisms were of only minor importance in the breakdown of aldrin. However, Lichtenstein & Schulz (1960) found that, whereas little aldrin was transformed into dieldrin in autoclaved soil, dieldrin gradually increased after 112 days, corresponding with an increase in numbers of microorganisms. Aldrin also disappeared much faster in non-autoclaved soil than in autoclaved, and in wet than in dry soil, perhaps because microorganisms are usually more active in wet than dry soil. A relatively persistent organo-phosphorus insecticide, Trithion, persisted much longer in soil which had been autoclaved or fumigated with sodium methyl dithiocarbamate (Menn *et al*, 1960).

Much more work is required on the subject of breakdown of insecticides by bacteria, but it seems probable that they may be responsible for many of the simpler degradations of these complex organic materials.

Until we know more of the factors which control the persistence of insecticides in soil, they should be used with caution because once applied they may remain for many years with little hope at present of accelerating their breakdown artificially.

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